SURFACE ALBEDO FORCING OF THE MARTIAN WATER CYCLE. L. K. Fenton[1], A. Colaprete[2], and M. D. Smith[3], [1]Carl Sagan Center/NASA Ames Research Center, MS 245-3, Mountain View, CA 94035, lfenton@carlsagancenter.org, [2]NASA Ames Research Center, Mountain View, CA, tonyc@freeze.arc.nasa.gov, [3]NASA Goddard Space Flight Center, Greenbelt, MD, michael.d.smith@nasa.gov.

Introduction: The present-day climatic state of Mars is produced by a complex interaction of surface and atmospheric processes. The behavior and coupling of these processes on seasonal timescales are partly understood, but drivers of interannual variations (particularly the dust cycle) are poorly understood. In this work we use the Ames Mars Global Circulation Model (GCM) [1] to demonstrate that observed changes in the surface albedo prior to and after the 2001 global dust storm (GDS) caused observed changes in the seasonal water cycle.

Albedo changes. For hundreds of years, ground-based astronomers observed shifts in the appearance of classical albedo patterns on Mars. In modern times, spacecraft data have revealed that these variations may be attributed to removal and deposition of bright dust on the surface, brightening or darkening large swaths of the surface by 10% or more [2-4]. Recent modeling has shown that the observed albedo changes between the Viking era of the 1970s and the early Mars Global Surveyor (MGS) era of the 1990s act as climate forcing on an interannual time scale, influencing wind stresses, dust devil formation, and likely contributing to the observed sublimation of CO_2 ice at the south polar residual cap [5].

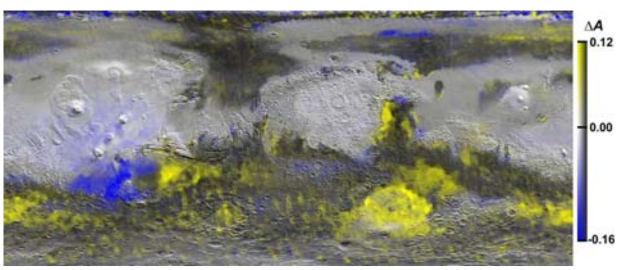

Figure 1. Changes in TES albedo (between latitudes ±80º) after the 2001 GDS. Many areas brightened (yellow), but a few darkened (blue). Most changes are within ±0.05.

Albedo changes continued during the MGS mission, most notably after the 2001 GDS, during which most surfaces brightened from dust fallout but a few darkened from dust erosion [4] (see Fig. 1). Thermal Emission Spectrometer (TES) data from MGS indicate that the net surface brightening lowered zonal mean (2PM) air temperatures in the post-storm season by 0-10 K [6], for the first time demonstrating that albedo changes on the surface can directly affect the atmosphere. Water vapor retrievals for the southern summer following the 2001 GDS indicate a depletion at high southern latitudes relative to the previous year, long after the end of the GDS itself. This is shown in Figure 2 (in the magenta box). Note that differences in water vapor during the 2001 GDS time period may or may not be “real” (i.e., the atmospheric dust may mask the spectral signature of water vapor, or the high dust content may cause errors in the retrieval algorithm).

The hypothesis that this work seeks to test is: *did the post-storm surface brightening and subsequent atmospheric cooling lead to lower atmospheric water vapor abundance, thus establishing another link between the dust and water cycles on Mars?*

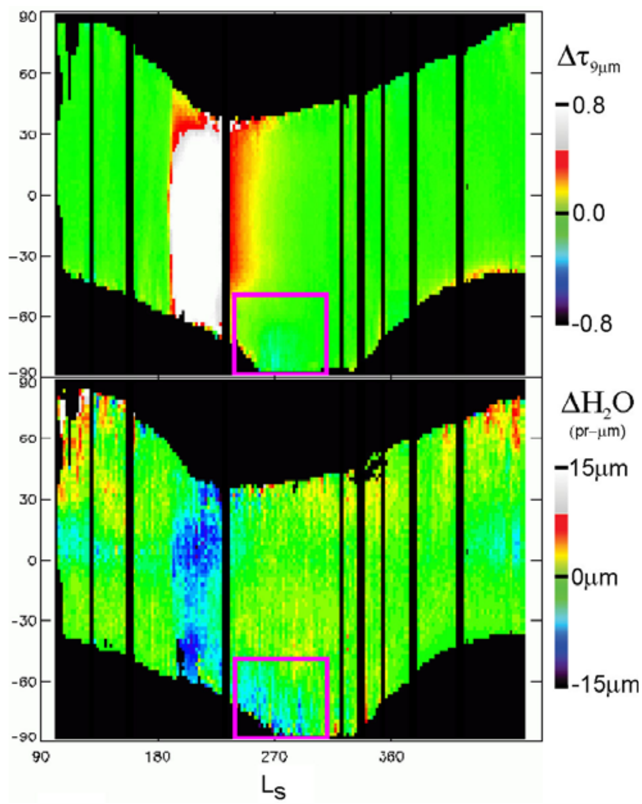

Figure 2. Zonal mean differences in TES retrievals between the year during and the year before the 2001 GDS. Δ9μm optical depth (top) and ΔH_2O vapor column abundance (bottom). Note high latitude depletion (blue/cyan) in southern summer H_2O in the season following the 2001 GDS, L_s=240º-300º (in magenta box).

Seasonal Water Cycle. Recent atmospheric modeling [7,8] suggests that the seasonal water vapor cycle on Mars may be briefly described as follows. The main (and perhaps sole) source of atmospheric water vapor originates in the north polar residual cap, a small amount of which sublimes each spring and summer, leading to a large main annual peak in water vapor column abundances at high northern latitudes. Some of this water is transported to the southern hemisphere by the cross-equatorial Hadley cell, where it condenses on the surface as a small part of the southern hemisphere seasonal ice cap (mostly CO_2 ice). As southern spring arrives, the southern seasonal cap retreats to higher latitudes, releasing water vapor through sublimation. Much of this water vapor is cold-trapped by the nearby retreating seasonal cap, recondensing at higher latitudes where the ice persists. When the southern seasonal cap finally sublimates completely, the remaining water ice is released in a high-latitude burst of water vapor, leading to a second, smaller water vapor peak.

It is this secondary southern summer peak that appears depleted in the year following the 2001 GDS.

GCM water cycle: The Ames GCM water cycle used in this modeling includes surface-atmosphere and atmosphere-cloud exchange. The surface-atmosphere exchange follows the approach described in [8]. The atmosphere-cloud exchange uses a hybrid-moment cloud model that combines a two-moment model (e.g., mass and number) with a traditional mass-bin model [9]. The model represents clouds as moments while calculating transport, but then switches to the mass-bin model for microphysical calculations. This approach allows for more detailed microphysics to be applied in a more traditional sense, while greatly reducing the computational time that would be associated with carrying multiple mass-bin dynamical tracers.

The model resolution is 5º latitude by 6º longitude resolution with 24 vertical layers. Each model run is initialized with a large (1000 kg m^{-2}) symmetric northern ice cap. The surface albedo is modified when water frost accumulation exceeds 10 µm to a constant value of 0.4. Atmospheric dust is taken from TES observations (TES year 1, or MY 25). In the polar night where no TES dust opacity information is available, a dust opacity is fixed at the pole and linearly interpolated to the nearest latitude containing TES observations. The dust opacity is also used to derive the number of nucleation sites for cloud formation [8]. For the simulations presented here a critical supersaturation for nucleation of 10% is fixed and a contact parameter of 0.95 is assumed.

GCM runs: The Ames GCM was run for two separate cases, each using TES albedo input maps from either the year before the 2001 GDS (equivalent to the standard TES albedo map data product available from PDS) or from the year following the 2001 GDS. Albedo maps were produced from TES Lambert

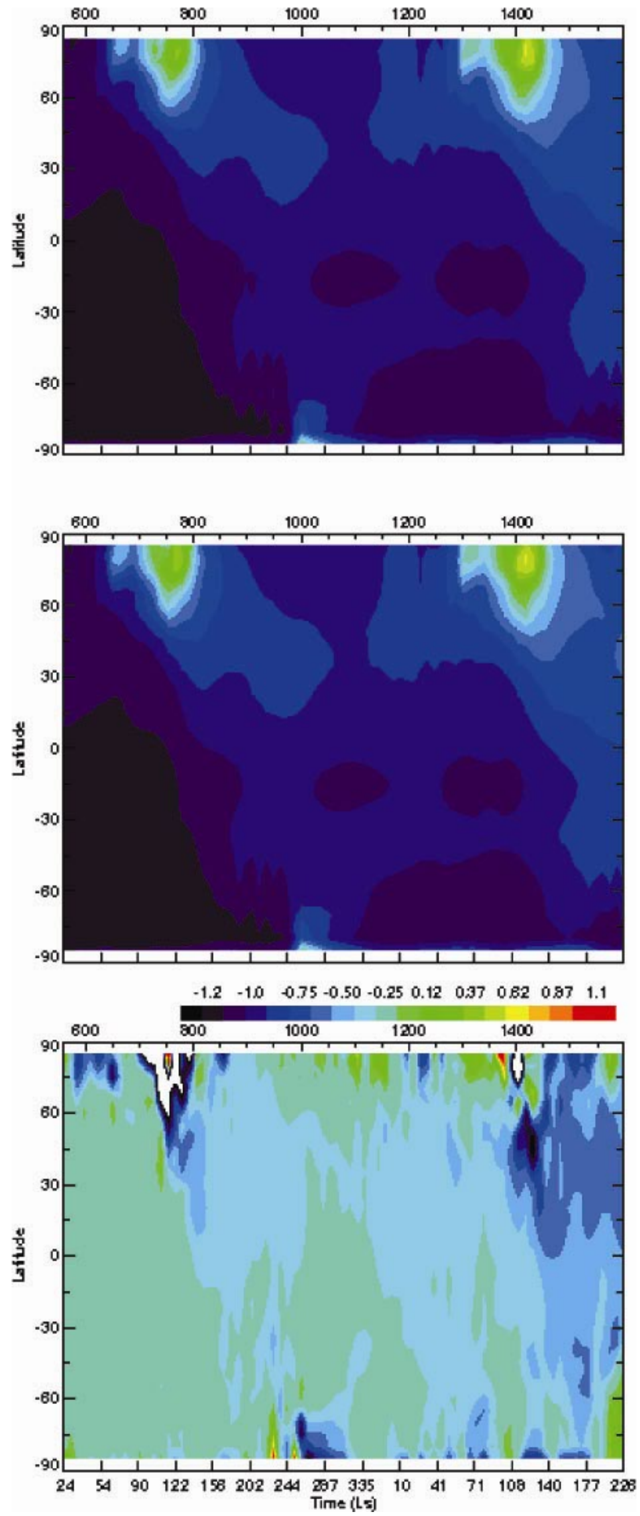

Figure 3. Second year (mid spin-up) GCM output showing zonal mean water vapor column abundances using pre-storm albedos (top) and post-storm albedos (middle), with differences shown at the bottom. Note the net depletion at high southern latitudes during southern summer (L_s = 244-335º).

albedos binned to 1ºx1º resolution, mostly using data from the northern spring season (except where necessary to fill in data gaps or locate nonicy surfaces).

It should be noted that albedos change with time, and thus a full year of GCM output with any given albedo map is not likely representative of a realistic annual cycle. For example, TES year 1 (pre-storm) albedos are more representative of the surface in the time leading up to the 2001 GDS, which began at L_s ~ 180º, whereas TES year 2 (post-storm) albedos are more representative of the surface in the southern spring and summer season following the storm. Because the 2001 GDS itself is not modeled in our GCM runs, we chose to run two separate cases, one with each albedo map, rather than to attempt to switch the albedo partway through a model run.

Global output was averaged over the course of the day and the daily average saved. To date, each of the two model runs has extended for just over two martian years. It is clear from the results that spin-up is not yet complete, and thus the reported work here must be treated as preliminary. We anticipate that more quantitative and complete results will be available at the date of the conference.

Results: Figure 3 shows water vapor column abundances from the two model runs (not showing the first spin-up year). The water cycle appears to be well represented in both albedo run cases, with the main water vapor peak occurring in the northern summer and being transported across the equator. The smaller, southern summer water vapor peak appears at high southern latitudes. The beginning of the next year appears on the right side of the plot, indicating a higher water vapor content in ensuing model years, with equilibration still a few model years off.

The bottom plot in Figure 3 shows the differences between the top plots (post-storm minus pre-storm albedo cases). By only the second spin-up year, a southern summer depletion in water vapor column abundance is visible. The difference is on the order of -1 pr-µm, but this difference is likely to grow in size as the water cycle ramps up over successive years.

Figure 4 more quantitatively demonstrates how a brighter Mars would influence water vapor in both hemispheres, if the higher albedos were to persist throughout the martian year. A brighter surface leads to atmospheric cooling, which sublimates less water vapor (solid lines in Figure 4) off both the northern permanent and southern seasonal ice caps, leading to an overall global decrease in water vapor.

The subsequent effect of albedo change on water clouds (dotted in Figure 4) appears to be both more subtle and complex than that of water vapor. The interaction between albedo, water vapor, and water clouds may depend on regional changes (e.g., did the albedos change in regions of extreme topography, enhancing local climates, or out on the plains?), and thus a full spatial and temporal investigation may be necessary to understand the net global changes reported here.

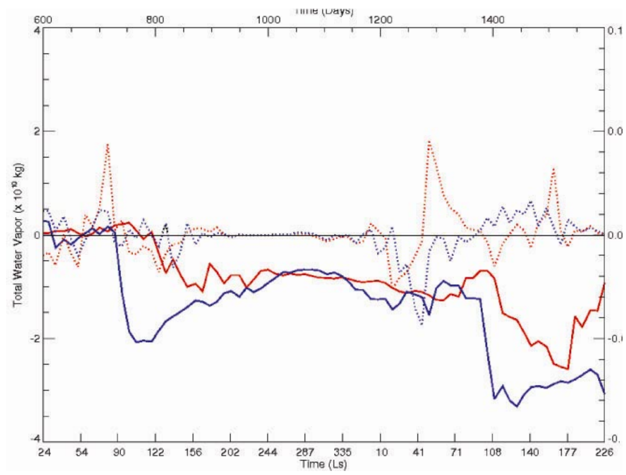

Figure 4. GCM run differences in total hemispheric (red for the southern hemisphere, blue for the northern hemisphere) water vapor mass (solid lines) and water clouds mass (dotted lines). The GCM run with higher (post-storm) albedos shows a net depletion in water vapor in both hemispheres, and an interesting interaction between water vapor and cloud mass during some seasons.

Summary: Preliminary modeling suggests that changes in albedo caused by dust fallout from the 2001 global dust storm is likely responsible for the observed drop in water vapor abundance at high southern latitudes in the southern summer following the storm. Surface brightening by a thin mantle of dust cooled atmospheric temperatures, likely decreasing the rate of water sublimation off the southern seasonal ice cap. Certainly the occurrence of the global dust storm itself influenced the water cycle during that year, but the global increase in albedo had ramifications that persisted throughout the season after the storm had dissipated.

This interaction between surface dust distribution and water vapor is a new link between the dust and water cycles, indicating that these climate-driving processes are coupled in more ways than previously thought.

References: [1] Haberle R. M. et al (1999) *JGR, 104*(E4), 8957-8974. [2] Christensen P. R. (1988) *JGR, 93*(B7), 7611-7624. [3] Geissler P. E. (2005) *JGR, 110,* E02001. [4] Szwast M. A. et al (2006) *JGR, 111,* E11008. [5] Fenton L. K. et al (2007), *Nature, 446,* 646-649. [6] Smith M. D. (2004), *Icarus, 167,* 148-165. [7] Richardson M. I. and Wilson R. J. (2002), *JGR, 107*(E5), 5031. [8] Montmessin F. et al. (2004), *JGR, 109,* E10004. [9] Colaprete A. et al. (2007), *Planet. & Space Sci.,* in review.